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THE PEOLE SATELLITE

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THE PEOLE SATELLITE

ABSTRACT. French PEOLE satellite will be placed in equatorial orbit by the DIAMANT B launch vehicle in December 1970. PEOLE launch inaugurates beginning of campaign of geodetic observations (ISAGEX) with 16 countries taking part. PEOLE satellite described including payload, fairing, power supply, telemetry, command guidance, service modules and pyrotechnical system. Experiments to be carried out will concern stabilization by gravity gradient and the localization system. Orbit of PEOLE (altitude 750-800 km, inclination 15 degrees) is first satellite for geodetic purposes to be launched with less than 28 degree inclination. Discussion of laser telemetry and space geodesy. The network of 63 sites taking part on a worldwide basis in the ISAGEX program is described with equipment allocated. Launch chronology provided.

Introduction

The second technological test of the French DIAMANT B satellite launch /5 vehicle will take place in December 1970. The operation will be terminated when the French PEOLE satellite is placed in equatorial orbit. The satellite will fulfill a dual mission:

it will allow flight testing of new techniques and equipment;

it will be used as a starting point for a worldwide campaign of geodetic observations.

The French DIAMANT B satellite launch vehicle was already successfully flight tested on 10 March 1970 (injection into orbit of the German DIAL/WIKA satellite). The second flight model only underwent some small-scale modifications, more particularly to suppress abnormal vibrations ascertained during operation of the first stage (L-17).

Following this second technological test, DIAMANT B will be used for the March 1971 launch of the French D-2A scientific satellite.

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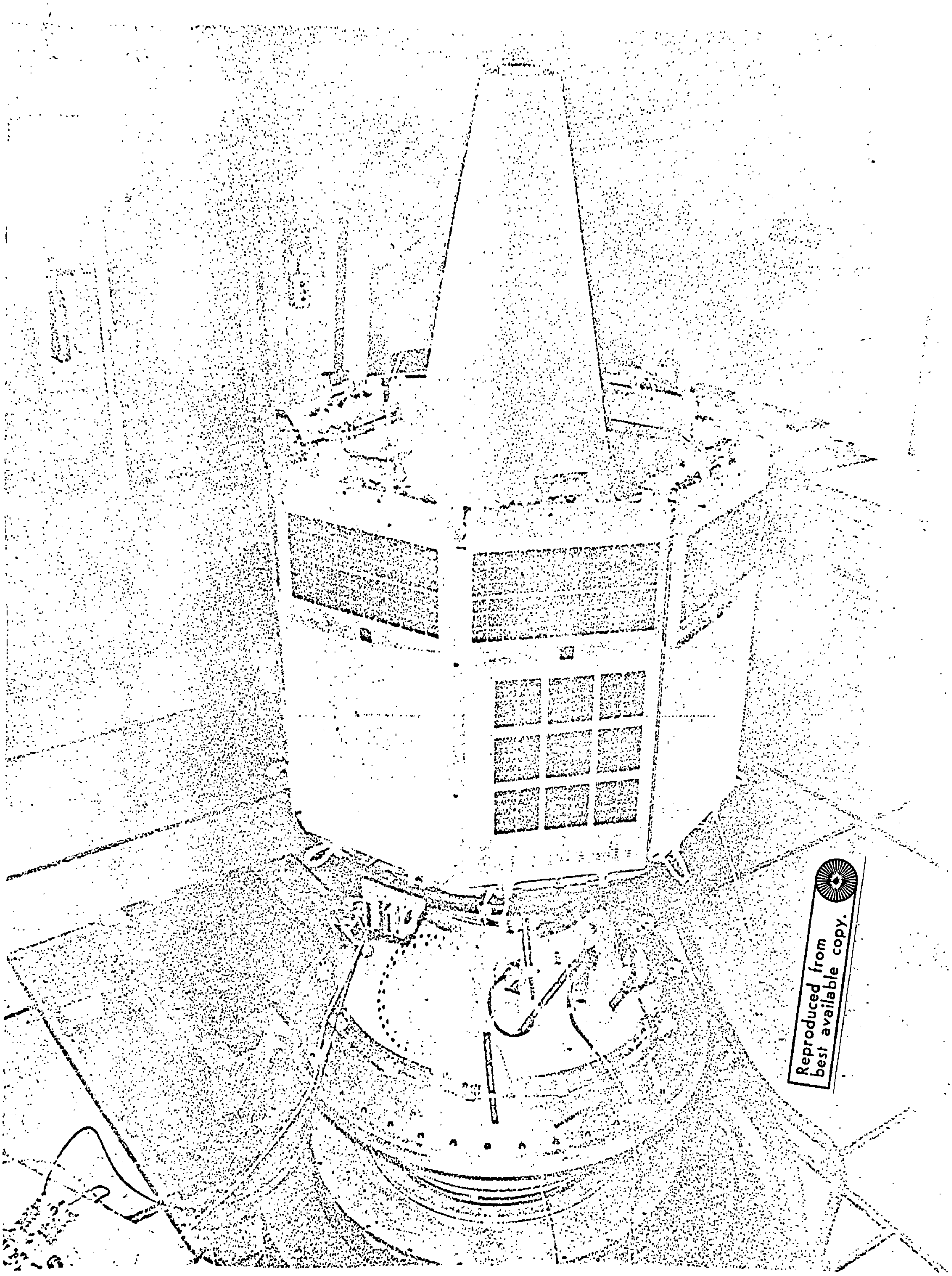
*Numbers in the margin indicate pagination in the foreign text.



The first flight testing of DIAMANT B likewise provided the Guiana Space Center with the opportunity for checking out the operational readiness of its equipment for such operations. This followed the successful launches of many sounding rockets. At the same time, construction continued on the base of the CECLES-ELDO European launch center.

The French PEOLE satellite makes up a flying test bench for new equipment and techniques. More particularly, the vehicle is the one used for the EOLE meteorological satellite and tests will be made of the system which will be used to ensure communication links between this satellite and the platforms (balloons) which the latter is to interrogate (whence the name PEOLE, Contraction of "Préliminaire á EOLE") as well as the stabilization system of this satellite.

The high altitude equatorial orbit (750-800 km) of PEOLE and the reflectors with which the satellite is equipped make this an outstanding instrument for space geodesy (laser telemetry).

The experience gained by France in the field of geodesy, especially with the DIADEME satellites, will be improved and carried forward within the scope of an international program.

The PEOLE launch will indeed correspond to the beginning of a worldwide campaign of geodetic observations (ISAGEX) in which 16 countries will take part and whose project chief will be CNES, also acting as main Center manager for operations as a whole.

The Payload

Two main requirements controlled production of the PEOLE satellite: /6

need for swift production (on the order of 15 to 20 months);

need for minimum cost.

Maximum use therefore was made of existing equipment, developed during preceding programs, or equipment already prepared for use within the scope of other projects.

The PEOLE vehicle is the qualification model of the EOLE satellite. Insofar as the electronics are concerned, wide use was made of FR-1 satellite equipment.

With only a few exceptions, the new equipment was produced at CNES. The very short time available occasionally led to the use for this equipment of "professional type" electronic components. For this reason, they do not provide the same guarantee of reliability as components produced for space applications. In general terms, the research and development program was reduced to the strict requirement minimum.

All these reasons point up the fact that the degree of reliability of PEOLE is probably less than the standard generally required for a satellite.

Nevertheless, this is still completely consonant with the fact that this concerns a payload which is to be injected into orbit during an experimental test of a launch vehicle still not considered as operational. The service life of the electronic equipment carried aboard is less than 2 months. Nevertheless, it should be noted that the geodesy by laser experiment, only using the satellite as a passive reflector carrier, can be protracted over a much longer period.

The payload (70 kg) includes the satellite fairing (10 kg) and the PEOLE satellite in its true sense (60 kg).

The Satellite Fairing

This concerns the D-2 satellite fairing. It is fitted with a Yo-Yo despin system as well as a pneumatic satellite fairing separation device.

A Yo-Yo device, located on a polygonal frame of the fairing, allows the roll rate of the third stage (after burn) satellite fairing system to be reduced.

The separation and ejection of the satellite is ensured by another device including a pyrotechnic release tape and a pneumatic actuator.

The PEOLE Satellite /7

While in orbit, the PEOLE satellite has the appearance of an octagonal based prism topped off with an antenna supporting cone at whose base 8 panels are spread out. A stabilization boom, adjustable in length, is located in the longitudinal axis of the satellite contrary to the antenna supporting cone.

General Description

The body proper of the satellite is formed by two aluminum alloy main structures.

The PEOLE internal structure is made up of:

one lower plate, with honeycomb construction, on which are fastened the 8 movable panels carrying the solar cells, laser reflectors and solar sensors;

one central tube inside of which are located the stabilization boom drive and the triaxial probe of the magnetometer;

one equipment mounting deck (likewise made with honeycomb construction), /8 connected to the central tube by a neoprene ring ensuring suspension of equipment during launch;

one central upper plate, fastened to the end of the central tube and on which the batteries are installed.

The external structure of the satellite now covers over the aggregate described above and is fastened down on its lower plate. This structure is made up by a "squirrel cage" with 8 surfaces on which 8 stationary panels are installed.

External coatings and internal radiation screens, fastened to the frames of the squirrel cage, allow passive thermal control according to the so-called "insulated core" principle which will be applied with EOLE (see page

The antennas. A spiral cone UHF (400-460 MHz) antenna is installed on the upper plate of the outer structure. The four leads of the telemetry antenna (VHF 136-148 MHz) are attached at 90° to one another, on four edges of the squirrel cage.

The device for extension and retraction of the boom, housed in the central tube of the satellite, includes:

one DC motor able to operate in a vacuum by means of special brushes;

one reducing gear;

one drum on which is wound the beryllium copper strip (tape) making up the boom;

one 3 kg weight released from its cavity by a vapor pressure device;

one potentiometer allowing remote measurement of length of boom.

Solar sensors (two per each panel) and one albedo sensor (on the upper cone) allow restoration of altitude.

Eight movable panels attached to the base of the satellite, each one having solar cells on both surfaces.

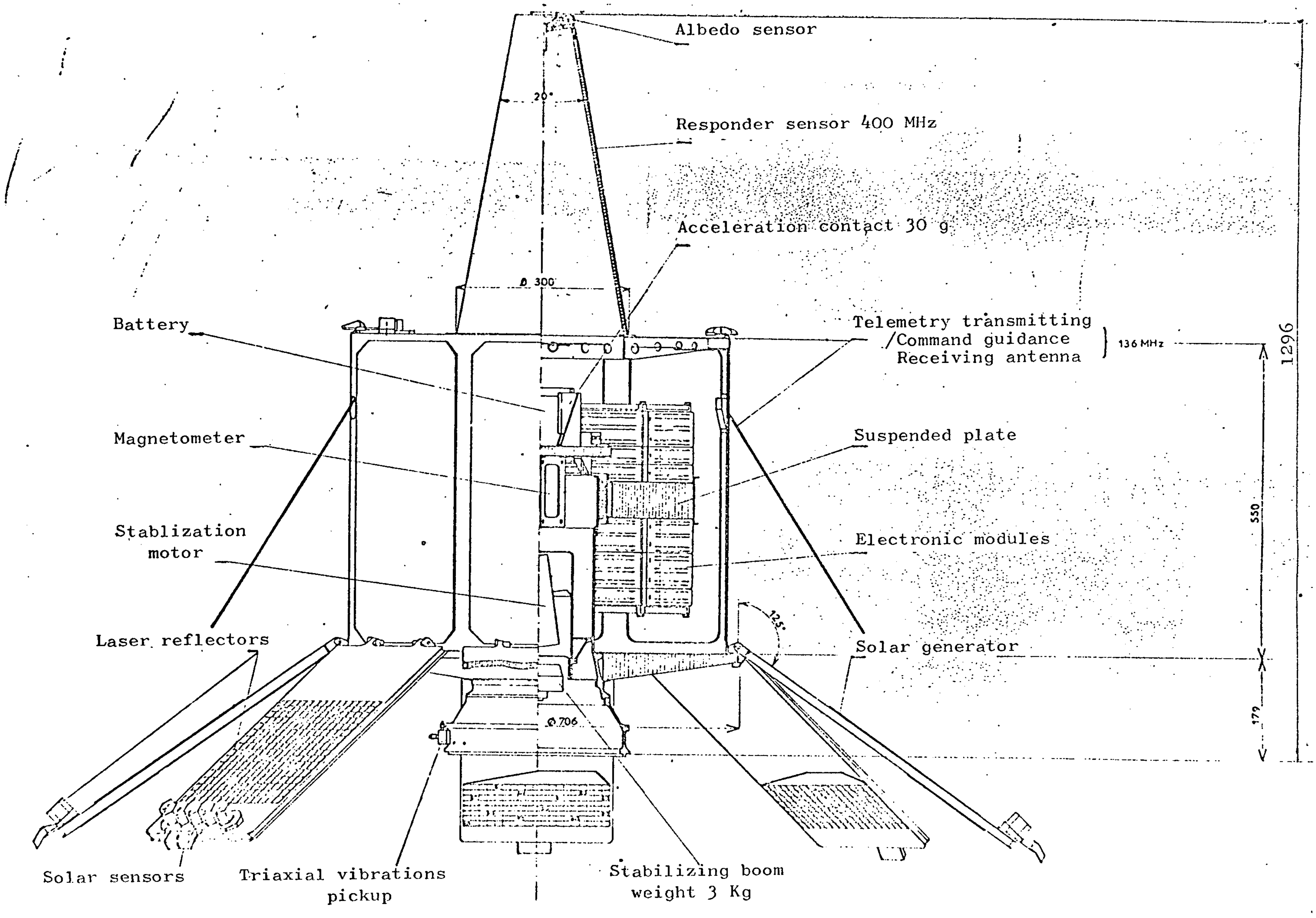
The 44 laser reflectors are divided into 8 groups of 5 (at the end of each movable panel) and 1 group of 4 at the foot of the cone antenna.

Electrical Power Supply

The electrical power supply system of the PEOLE satellite essentially includes one solar generator, one battery, several converters and devices protecting the battery against extreme voltages.

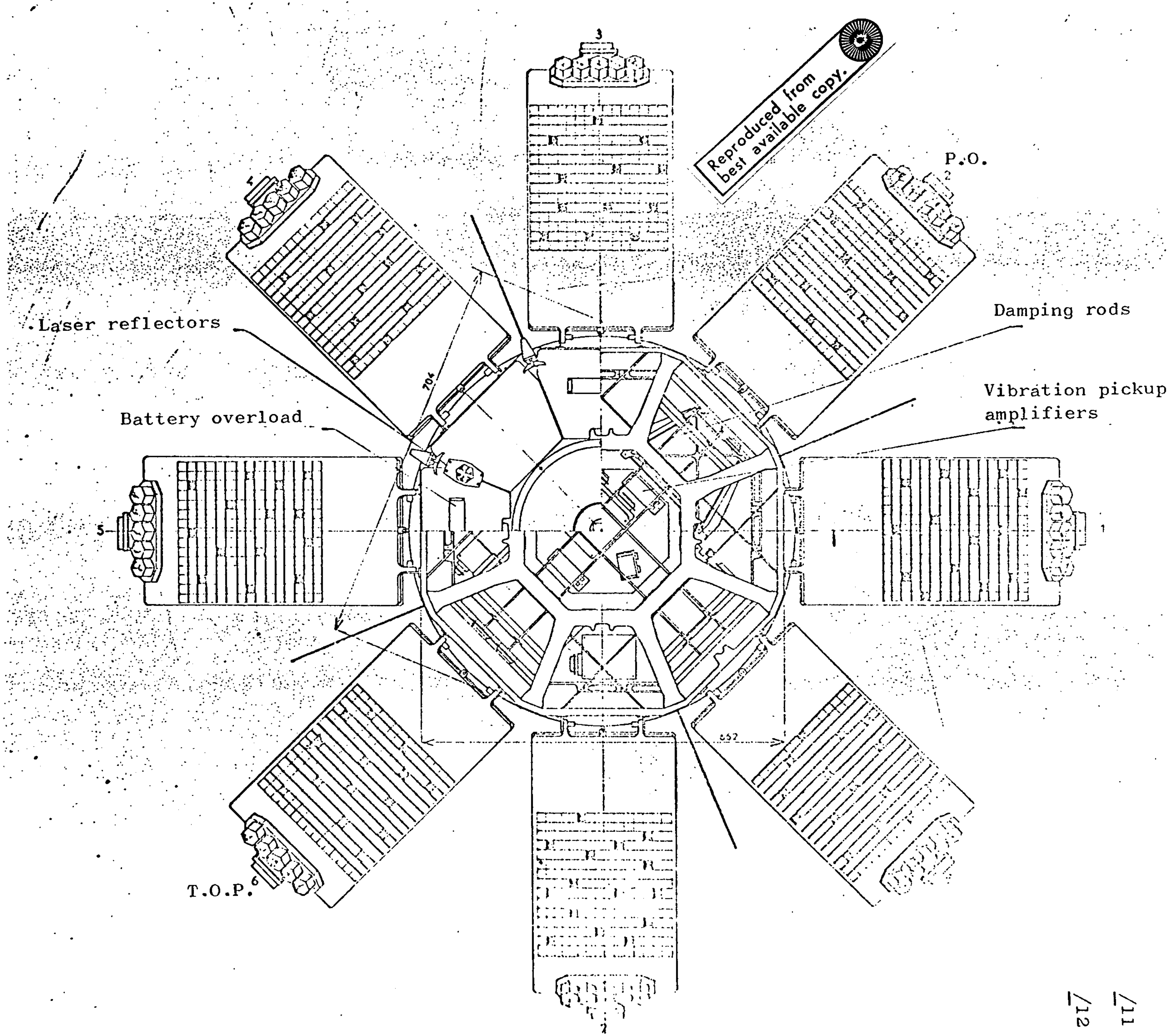
The solar generator (2016 cells using silicon as the basic material, of n- and p-type and protected by a blue filter 150 microns thick. The basic resistivity, 10 ohms/cm, supplies, when the satellite is stabilized, a mean power on the order of 15 to 20 W.

Power is stored in a silver-cadmium battery (9 cells with 5-amp/hr


Albedo sensor
20°
Responder sensor 400 MHz
Acceleration contact 30 g
Ø 300
Battery
Telemetry transmitting
/Command guidance
Receiving antenna
136 MHz
1296
Magnetometer
Suspended plate
550
Stablization
motor
Electronic modules
125°
Laser reflectors
Solar generator
Ø 706
179
Solar sensors
Triaxial vibrations
pickup
Stabilizing boom
weight 3 Kg

7

10
9


3
P.O.
2
Damping rods
Laser reflectors
704
Vibration pickup
amplifiers
Battery overload
5
1
652
T.O.P.
6
7

/11
/12

capacity, enclosed in an epoxy resin coated aluminum battery pack). Two thermisters (temperature measurement and overvoltage detection) are located in the middle of the battery. The depth of discharge (ratio of battery capacity during the night with its total capacity) amounts to 15% (0.7-amp/hr). /13

One monitoring converter powers the command guidance and decoder receiver and is connected directly to the battery terminals. It is permanently energized.

The 2 other converters of the satellite are only powered on command:

one main converter supplying the various voltages required for the system of equipment with the exception of the command guidance system (monitoring converter) and the responder transmitter;

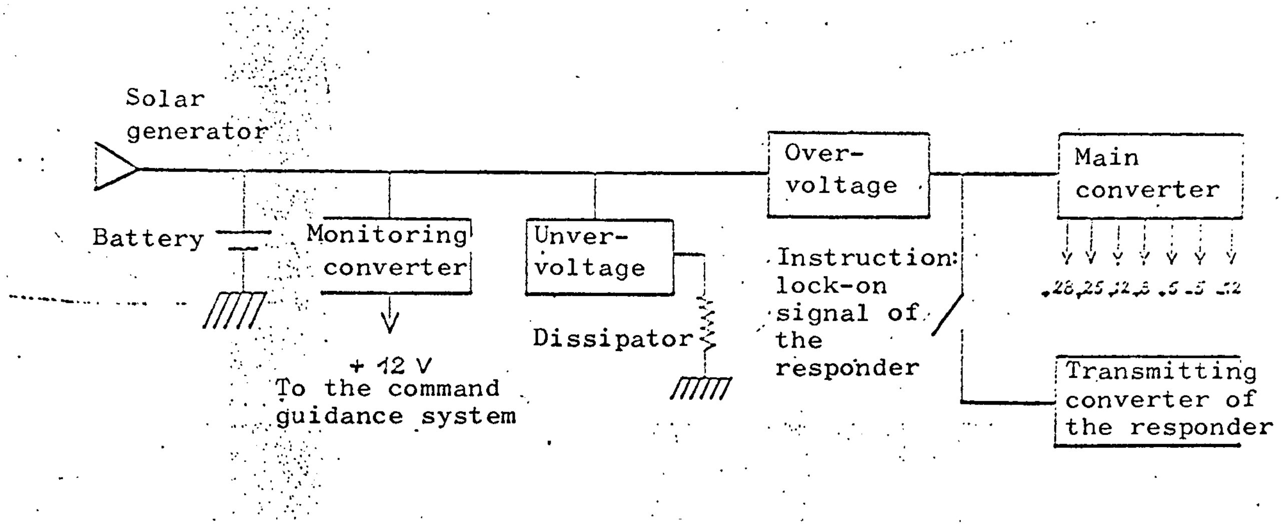
one converter energizing the power stages of the responder transmitter.

This latter converter is placed under load when the responder receiver is locked on to an incoming signal. It is switched off when this signal disappears.

The power supply system includes, in addition, 2 battery protective devices, one against undervoltages and the other against overvoltages.

The first one (module from the FR-1 satellite) switches off the power supply from the satellite assembly (with the exception of the command guidance system) when the battery voltage drops below 8.25 V. Under these conditions, a 10 hour timer commences operation and the power supply relay is only re- /14
switched in again after this lapse of time. It is nevertheless possible to operate the relay by command guidance, this being the way that the main converter is normally switched on and off.

The second device (module of the FR-1 satellite) prevents the battery voltage from exceeding 13.8 V, since this value is adjusted as a function of battery temperature. Three dissipators remove the excess power supplied by the solar generator in the event the battery is completely charged.



Telemetry

The PEOLE satellite has a phase-modulated (1 W at 136 MHz) telemetry transmitter.

The 2 telemetry coders (FR-1 coders) are used alternately. The selection of the telemetry transmitted is accomplished with a command guidance instruction.

Telemetry transmitter No. 1 is of the PAM/FM/PM type. The coder has 52 inputs. The data transmitted is shown in the figure below.

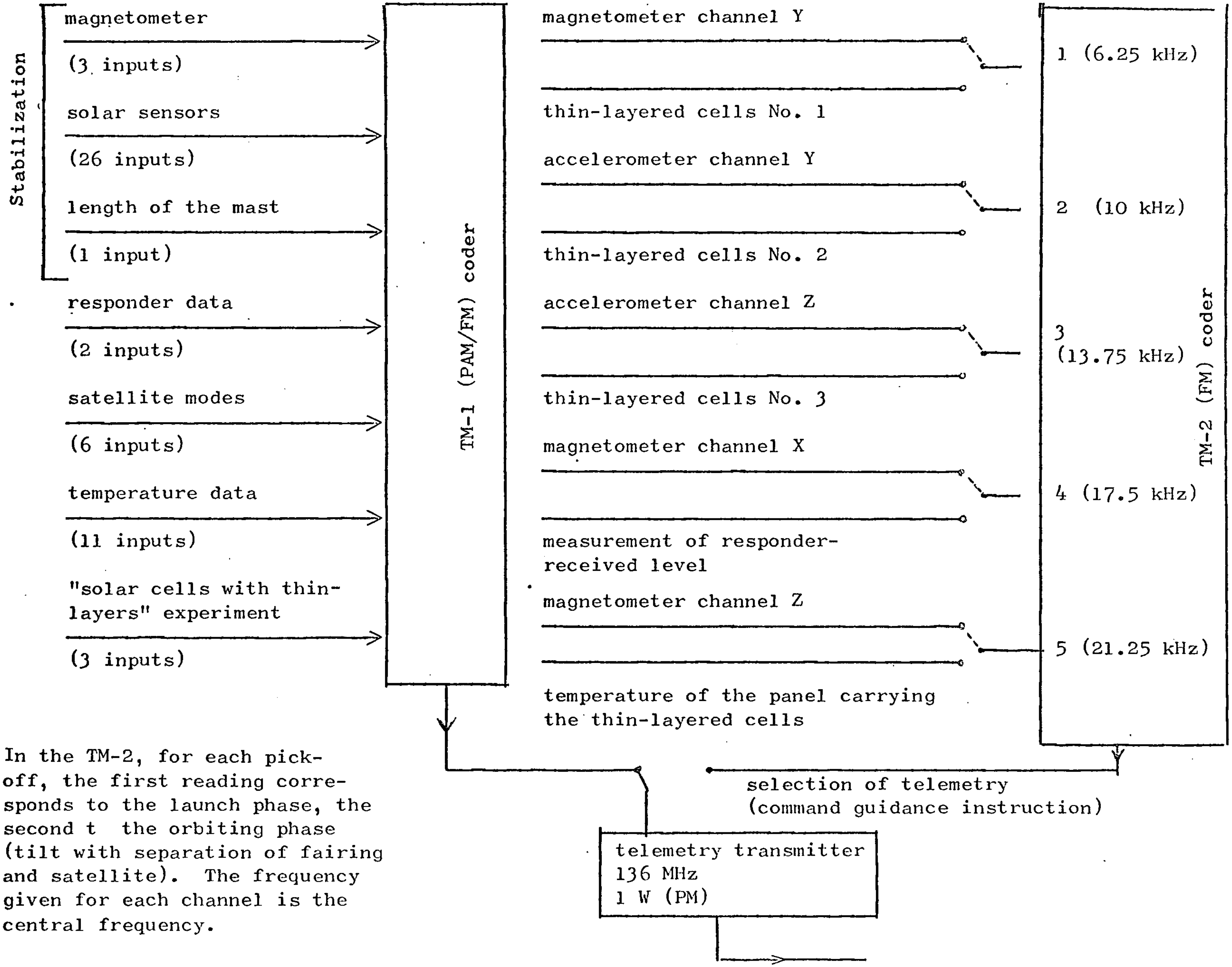
Telemetry transmitter No. 2 is a wideband (from 0 to 200 Hz) telemetry transmitter of the FM/PM type. It has 5 inputs. Each signal modulates with VCO[1]. The values of each of the 5 central frequencies are: 6.25, 10, 13.75, 17.50 and 21.25 kHz.

During the launch phase (up to separation of fairing and satellite), telemetry provides:

reading of vibration pick-offs, one located along the longitudinal axis and the other along one of the transverse axes;

data from the triaxial probe of the magnetometer, parameters which are

1. Voltage controlled oscillator.



In the TM-2, for each pick-off, the first reading corresponds to the launch phase, the second t the orbiting phase (tilt with separation of fairing and satellite). The frequency given for each channel is the central frequency.

/15

advantageously forwarded by a wideband technique.

During the orbiting phase, one of the channels is assigned to the amplitude detector of the responder (whose reading is the reflection of the HF level received by the responder). A wideband telemetry transmitter allows monitoring of possible high-speed fluctuations of the level received. The other channels are assigned to the solar cells "with thin layer" experiment whose parameters vary quite slowly, therefore not requiring a very wide band.

Command Guidance

The system is the one used for the FR-1 satellite (receiver and decoder). The command guidance is of the double tone type (address and execution). The receiver receives a carrier amplitude modulated at 148.980 MHz. Since the number of functions to carry out are greater than for the FR-1, a command multiplier performs, beginning from combinations of simple commands (at the outputs of the decoder), the different functions desired (execution of pyrotechnical commands directly following injection into orbit, applying voltage to or halting the main converter, selection of the telemetry coder, selection of a responder configuration causing the boom extender to start, stop or reverse).

Service Modules /16

FR-1 module, for measuring the different power supply currents;

PEOLE module, for measuring various thermistors of the satellite in order to restore temperatures;

transfer module which ensures, at the instant of separation of fairing and satellite, the switching over of signals assigned to the TM-2 during the launch phase to signals to be transmitted during the orbiting phase.

Pyrotechnical System

A timer which has been started while the satellite is still on the ground (at H-40 sec) triggers the firing of the explosive bolts allowing release of the Yo-Yo despin device, then separation of the fairing and satellite and, finally, the spreading out of the solar panels. The timer and its related equipment (battery, acceleration contact...) are those used in the D-2.

In the event the timer has not operated, it is possible to cause the pyrotechnical instructions to be carried out by command guidance since the "timer" and "command guidance" units are independent in the module.

Technological Experiments

/17

One of the essential goals of the PEOLE mission is to flight qualify the gravity gradient stabilization device and the localization system which will form part of the equipment of the EOLE meteorological satellite. A technological experiment, designed to study the space environmental aging of 2 small solar generators using sulfur and cadmium telluride based thin-layer cells, is likewise placed on board.

Stabilization by Gravity Gradient

The EOLE satellite, from which PEOLE takes its origin, is to be used to localize terrestrial or near terrestrial (balloons) platforms. The antenna of the localization systems embarked on the satellite should therefore be constantly aimed towards the earth and its axis oriented according to the local perpendicular. A gravity gradient stabilization system allows achievement of this goal.

Gravity Gradient Stabilization Principle

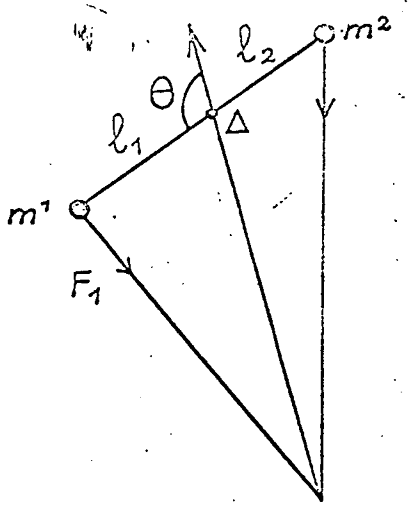
At a distance $\vec{R}$ from the center of the earth which is assumed spherical and uniform, with μ designating the terrestrial gravitational constant, the acceleration of gravity is: $\vec{g} = -\mu/R^3 \vec{R}$. The value of this vector varies from one point to another of the satellite since some points are farther removed than others from the earth's center. The system of gravitational forces will be reduced to one force and one torque applied to the center of inertia of the body. This will be the phenomenon used in gravity gradient stabilization.

More precisely, let us assume that a body is placed in orbit which is made up of two masses m_1 and m_2 connected by a stiff rod whose mass can be disregarded. It can be proven that the torque of the gravity gradient is given by:

$$C = -3\mu \, (R_0{}^3 \, I \sin\theta \cos\theta)$$

I is the moment of inertia ($= P_1 M_1 + P_2 M_2$)

A is the center of inertia of the body.



The restoring torque is zero for $\theta = \pm \pi/2$ and $\theta = 0 \pm k\pi$ corresponding to a position of equilibrium. Nevertheless, only the $\theta = 0 + k\pi$ case corresponds to a stable equilibrium. The rod will take its direction depending on the perpendicular of the place with indiscriminately m_1 or m_2 closer to the earth. /18

The satellite has been given a configuration which closely resembles the latter: one of the masses is formed by the body of the satellite (with the antenna to be directed towards the earth), the other by a weight connected to the main body by a boom (similar to the rod with negligible mass). The system will be positioned such that the boom merges with the local perpendicular. As we have pointed out, there are 2 positions of stable equilibrium with only one being suitable (satellite's antenna directed towards the earth).

The boom of the PEOLE has a length of 10 m. The weight has a 3 kg mass which provides, taking into account the characteristics of the satellite's body, a moment of inertia with respect to the roll and pitch axes of $I \simeq 300$ kg·m^2 whence a restoring torque of $C = 15.10^{-6}$ N m/degree, which is extremely small.

The Disturbing Torques. This extremely small restoring torque explains the great sensitivity of the system to disturbing torques.

The following mentioned are disturbing torques:

torque of magnetic hysteresis. The satellite is fitted with 16 magnetic rods (in order to damp its initial motion). Once stabilization has been achieved, these rods tend to be directioned according to the magnetic field, whence the creation of a torque;

torques owing to the residual magnetic dipole. The satellite is not magnetically clean. It is equivalent to one dipole which is affected by the earth's magnetic field. All components are magnetically as clean as possible, more particularly the battery of the silver-cadmium type;

torques owing to eccentricity of orbit;

torques owing to forces of aerodynamic pressure;

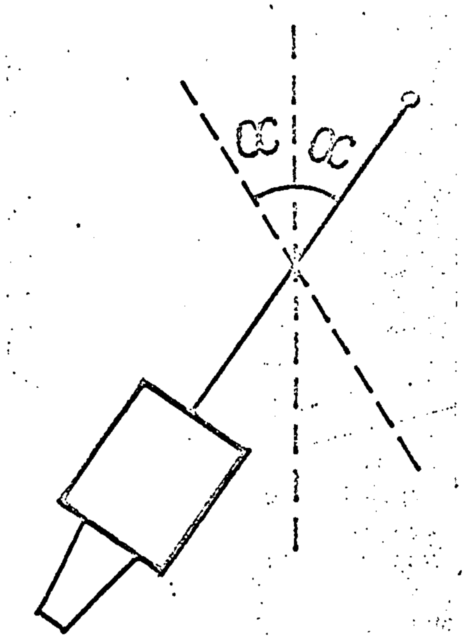
torques owing to forces of pressure of solar radiation (5 times less than the preceding ones);

torques owing to deformations of the stabilization boom (natural static, static thermal and dynamic thermal deformations).

Since the gravity gradient torque is small, the stability conditions should be studied most carefully in order to avoid a condition in which an addition of disturbing torques leads to an inopportune reversal of the satellite. At any rate, these disturbing torques act upon the system by causing it to oscillate like a pendulum. This amplitude varies with time depending on how the disturbing torques are added together. In PEOLE, the maximum expected amplitude is such that α is on the order of 10 to 15 degrees. The locatization antenna has a rather wide aperture angle and a directional error of 10 to 15 degrees which does not perceptibly interfere with the link.

<u>Acquisition of Stabilization</u> /19

During launch, the boom is wound on its drum. The weight is integral with the satellite body (a pellet of sublimable material holds together the locking system of the weight).



Stabilization is acquired as a result of operations which, following injection of the satellite into its orbit, cause it to pass from the launch configuration to the stabilized configuration (boom extended and system positioned in the proper direction).

During launch the 3rd stage satellite-fairing system is spin-stabilized (at approximately 180 rpm). Following injection into orbit (end of 3rd stage burn), this spin stabilization is no longer required and it is slowed down by releasing the Yo-Yo despin device. The residual velocity (which ideally should be zero) is on the order of 1 to 2 rpm. Finally, the fairing is separated from the satellite and the movable solar panels are deployed.

Subsequent to these operations, the satellite still spins at a rate which is still too great for it to be possible to extend the boom. In reality, in order to start extension of the boom it is necessary for:

the residual angular velocities to be compatible with the mechanical behavior with bending of the extensible boom;

the total energy of the satellite, once the boom is extended, to be less than a certain so-called "energy of capture" value.

This energy includes:

the relative kinetic energy with respect to the local orbital pitch, roll and yaw axis;

the potential energy of the gravity gradient torques;

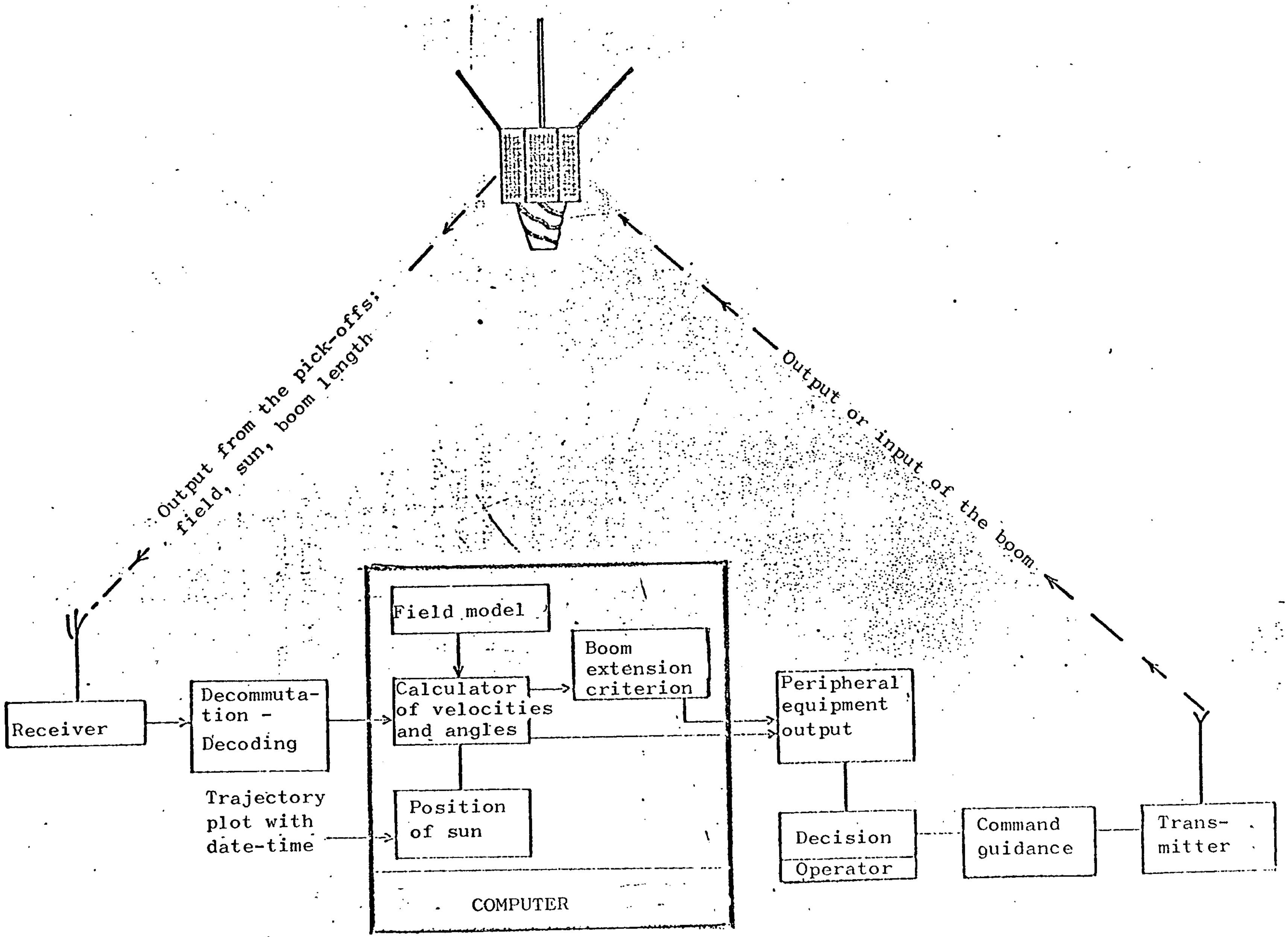
the driving energy of the orbital pitch, roll and yaw axis.

When the kinetic energy is too great, the restoring torques owing to the gravity gradient will not be strong enough to prevent the satellite from continuing its spin.

It is therefore necessary, after injection into orbit and before attempting /20
to extend the boom, to dissipate a good share of the kinetic energy. In order to do this, magnetic rods are used which dissipate the energy by hysteresis when they move around in the terrestrial magnetic field.

It is only possible to extend the boom when the residual velocity along the 3 axes is on the order of 10^{-3} radian/sec. It takes approximately 2 to 3 days to achieve this residual velocity.

Once this residual velocity is sufficiently low, it is possible to extend the boom. It is still necessary to do this in a manner such that stabilization is achieved with a good configuration in which the antenna faces the ground. It is therefore required to know the satellite's altitude before the extension maneuver. For this purpose, the satellite is furnished with solar sensors and a magnetometer which allow a plot of the altitude. In other words, a deter-


Output from the pick-offs:
field, sun, boom length
Output or input of the boom
Receiver
Decommuta-
tion -
Decoding
Trajectory
plot with
date-time
Field model
Calculator
of velocities
and angles
Boom
extension
criterion
Position
of sun
COMPUTER
Peripheral
equipment
output
Decision
Operator
Command
guidance
Trans-
mitter

/21
/22

mination is made on the ground of the position of a trihedron related to the satellite according to measurements made on board of the two reference directions (sun and magnetic field).

Before extending the boom, it is therefore necessary:

to know the satellite's altitude and angular velocities;

to calculate by means of this data, the total energy which the satellite would have if the boom were extended ("conditional energy") and to compare it with the "capture energy;"

to confirm orientation of the satellite's axis.

These operations should be carried out during a same pass above a site where it is possible to process telemetry data, calculations and transmission of command guidance instructions.

The calculations are performed in "real time" and this operation therefore involves extensive resources. The operational flowchart is provided by the figure below. In the case of PEOLE, the boom extension operations will be controlled from the Guiana base.

The boom's extension should be carried out when $E_{conditional}/E_{capture} < 1$ and, preferentially, when this ratio passes through a minimum - and, of course, only when this minimum corresponds to the proper position of the satellite (antenna towards the earth).

We can see four possible cases in the flowchart below.

When case A occurs at the acquisition site, the situation is favorable for extension of the boom (well-oriented satellite). On the other hand, when the boom is extended with case B, there will be stabilization, but in reverse.

The gradual development of $E_{conditional}/E_{capture}$ is followed at the site after the 2 or 3 days anticipated for damping the spin.

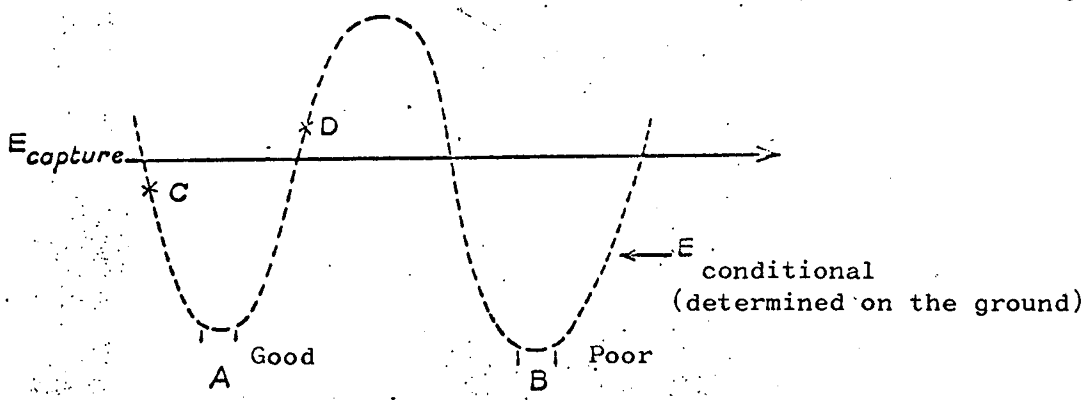
When a type A situation occurs, the extension of the boom is carried out by command guidance: this is direct acquisition. However, it can very well happen that, after a period which we have specified to be 3 or 4 days, such /23
a situation has never occurred at the site. The only case encountered was of

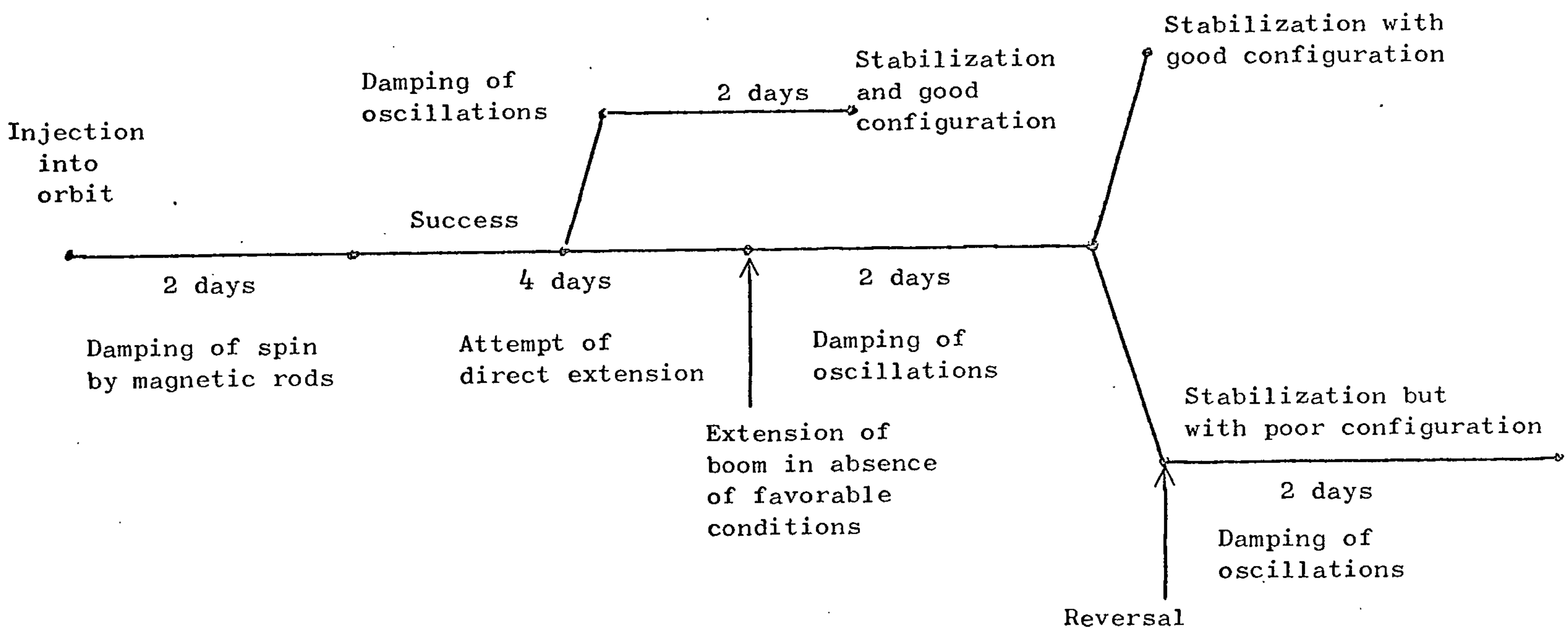
the type C or D. This is a case which is, in principle, favorable but to a limited extent. Taking into account errors made with measurement of parameters, this can very well be, in reality, an unfavorable case ($E_{conditional}/E_{capture} >$ > 1). Command guidance causes extension of the boom. When $E_{conditional}/E_{capture} >$ > 1, acquisition of stabilization is not immediate. The satellite, with boom extended, spins a few times and is finally stabilized with a probability of 0.5 that it will be properly oriented.

When the satellite is stabilized upside down, a reversal maneuver must be performed. It is expected that the oscillations (becoming substantial directly after capture) will be damped.

If these oscillations are disregarded, the spin rate of the satellite equals the orbital angular velocity ω_0. When the boom is retracted, inertia decreases and the rate of spin increases. By suitably reducing the inertia, it is consequently possible to cause the satellite to make a half turn on itself. When this half turn is complete, the boom is extended and the satellite is properly stabilized. When the initial oscillations and rates of extension and retraction of the boom are perfectly known, it is possible to carry out the reversal according to a "blind" procedure. The boom is retracted. A precalculated time T is waited and then the boom is again extended. When, on the contrary, the amplitude of the oscillations is great (this is the case with PEOLE which is poorly pitch-damped owing to its equatorial orbit; horizontal terrestrial magnetic field), the waiting time cannot be precalculated. It is necessary to follow the reversal in real time and do this not withstanding the fact that the voltage of the extension motor is not stabilized and the extension rate is therefore inaccurately known.

In summary, on a chronological basis, the maneuvers take place as shown in the flowchart below with the whole operation requiring from 2 to 10 days.




Injection into orbit
2 days
Damping of spin by magnetic rods
Success
Damping of oscillations
2 days
Stabilization and good configuration
4 days
Attempt of direct extension
Extension of boom in absence of favorable conditions
2 days
Damping of oscillations
Stabilization with good configuration
Stabilization but with poor configuration
2 days
Damping of oscillations
Reversal

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Localization System

/25

PEOLE is to allow flight evaluation of performances in the localization system of project EOLE. In the EOLE system, measurements are made on a round trip path between the satellite and the platform which will be the nacelle of a balloon in the initial meteorological experiment. The flight testing of this system could have led in fact to the production of a true EOLE satellite. An unusual solution was therefore conceived. It consists in "reversing" the radio-electrical link. An equipment reproducing all the functions of the EOLE satellite will be installed at the Kourou site and the PEOLE satellite will carry a responder performing the functions of the nacelle.

Localization Principle

The altitude of the platform to be localized is assumed known independently of the system, i.e., the platform is on a sphere T with center O (center of the earth) and with radius R and h.

At an instant t_0 (satellite with S_0), two types of measurements are carried out:

a Doppler measurement and

a measurement of the satellite-platform distance.

The measurement of the Doppler shift allows recovery of the relative satellite-platform velocity or, when the velocity vector of the satellite is known, the angle α of this velocity vector with the satellite-platform direction:

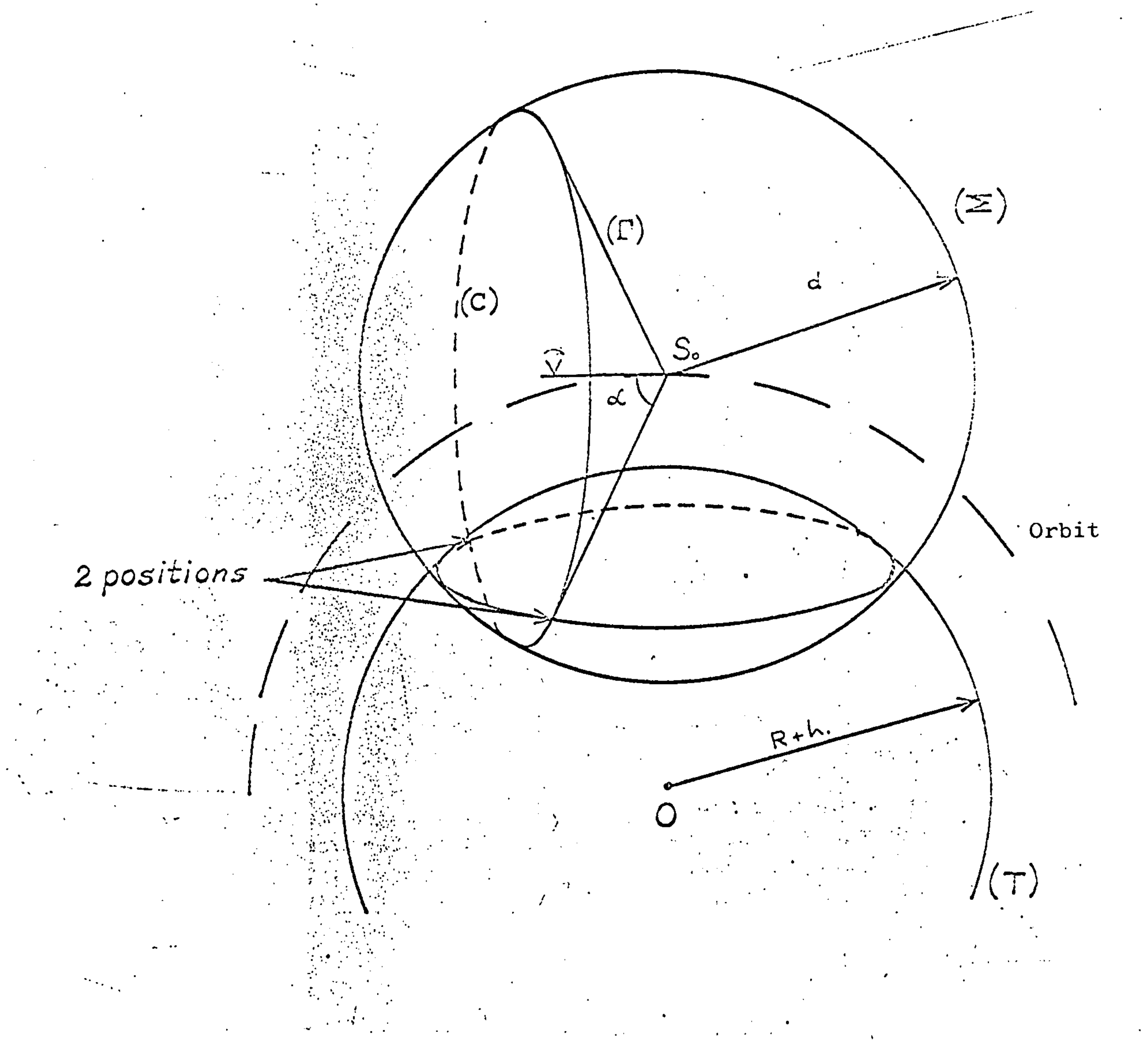
$$\Delta f = \frac{f_0}{c} \left|\vec{V}_s\right| \cos \alpha, \text{ in which}$$

f_0 is the transmitting frequency and c the speed of light.

It is therefore possible to locate the platform on a cone (Γ) with vertex S_0 and semiangle at vertex α.

The measurement of satellite-platform distance (d) likewise allows locating the platform on a sphere (Σ) with center S_0 and radius d.

(Γ) and (Σ) intersect according to a circle (C) which itself intersects sphere (T) at two points, one of which represents the position of the platform. Another measurement system allows removal of uncertainty.


(Σ)
(Γ)
(C)
d
$\vec{V}$
S_0
α
Orbit
2 positions
R+h.
O
(T)

The receiver-transmitter P_2 forms one coherent responder. Indeed, the retransmitted frequency is only a function of the frequency received. It is not a function of other frequencies. More particularly, there is no independent oscillator in the responder, meaning not coherent with the received frequency. Retransmission is therefore:

$$\mu/q\ (f_O + \Delta fd_a).$$

The incoming path is likewise affected by a Doppler shift and the frequency /27
which is a derivative of the received frequency:

$$\mu/q\ (f_O + \Delta fd_a) + \Delta fd_r.$$

(Δfd_r is the Doppler shift on incoming path).

It follows that $\Delta fd_T = \Delta/q\ \Delta fd_a + \Delta fd_r$ = total Doppler shift.

On an outgoing-incoming path, it can be shown that:

$$\cos\alpha = \frac{C}{|\vec{V}_s|}\left[\sqrt{1 + \frac{\Delta fd_T}{\mu/qf_O}} - 1\right].$$

Platform P_1 includes a counter which, by comparing f_O and f_{P_1}, allows Δfd_T to be known.

<u>Distance measurements</u>

Distance measurement is based on phase lag measurements of subcarriers. When a subcarrier is transmitted on $2\pi\ F_A t$ from platform P_1, after a trip out and back, it will return to P_1. The time needed for round trip transit Δt is connected to distance $2d = C\ \Delta t$.

The platform P_1, at any given instant t, transmits one subcarrier $2\pi\ F_A t$ and receives one subcarrier $2\pi\ F_A(t-\Delta t)$.

The phase lag Φ_A between these two subcarriers is such that $\Phi_A = 2\pi\ F_A \Delta t$, whence Δt is known and d : $d = \frac{\lambda_A}{2\pi}\frac{\Phi_A}{2\pi}$.

A phasemeter embarked on platform P_1 allows this phase measurement.

The system in reality includes 3 subcarriers and the calculations are performed beginning from phase lags with 3 subcarriers. The first one, with low frequency (F_Δ = 48 Hz), allows a coarse distance determinator. The precision is improved by a second subcarrier with F_B = 384 Hz. An additional improvement is contributed by the third subcarrier at 4992 Hz (each frequency plays, with respect to the preceding one, the role of a vernier). In reality, the two latter subcarriers are not transmitted. F_0 = 2304 Hz and F_1 = 2688 Hz are transmitted and phase lags Φ_0 and Φ_1 are measured on these two subcarriers $F_B = F_1 - F_0$ and $F_c = F_1 + F_0$. Consequently, the phase lags to be considered in the calculations are:

$$\Phi_A,\ \Phi_B = \Phi_1 - \Phi_0 \text{ and } \Phi_c = \Phi_1 + \Phi_0.$$

The advantage of transmitting F_0 and F_1, with neighboring frequency, rather than F_B and F_c, is a technologically involved problem (the electronic circuits to be used in the equipment are the same. Only the adjustments change).

The modulation transmitted by P_1 and retransmitted by P_2 is a "burst-blank" type modulation at a frequency of 48 Hz. The bursts either contain the frequency F_0 or the frequency F_1. Six F_0 bursts are passed in succession, then six bursts of F_1, etc. F_0 and F_1 are not transmitted simultaneously, this only leading, however, to an error which can be disregarded. /28

Equipment of the Two Platforms (Satellite and Site)

The main platform (site on the ground at Cayenne) includes:

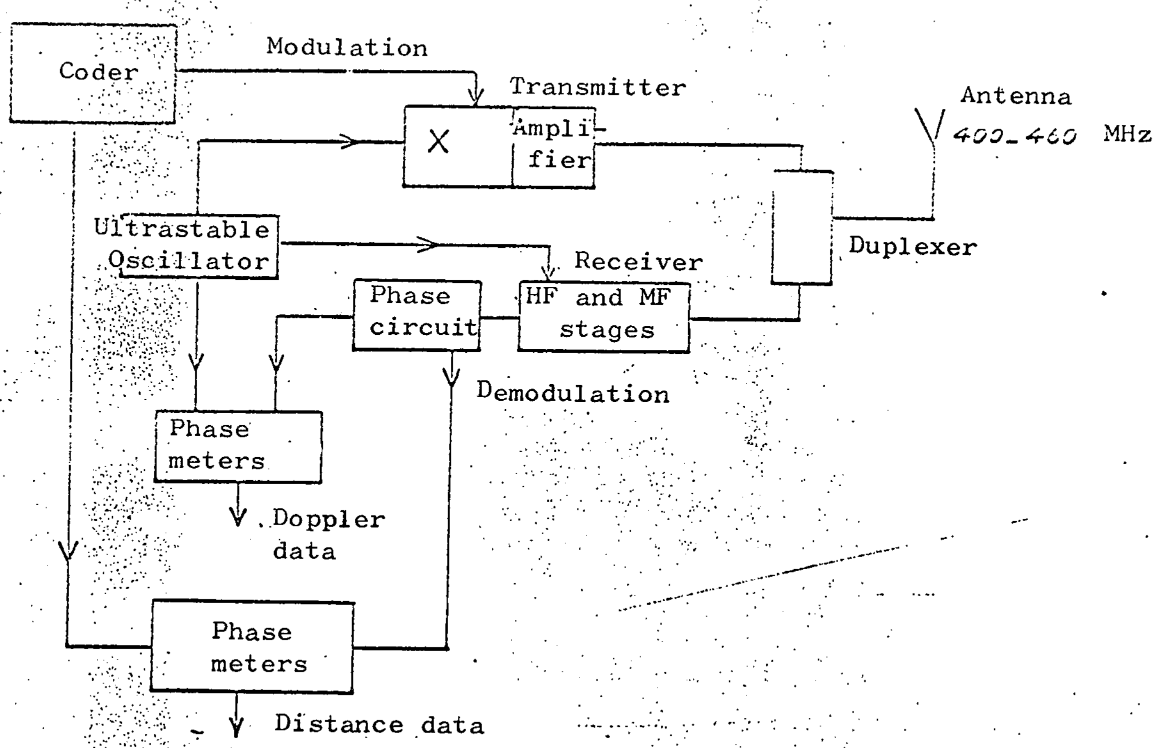
one ultrastable oscillator (all system frequencies derive from it);

one transmitter with its multiplying stages which, beginning from frequency f_v of the ultrastable oscillator, generate a signal at transmission frequency f_0 = 462.270 MHz with a power of 4 W;

one receiver which receives, amplifies and transposes in frequency the signal sent back by the responder;

one phase circuit directly following the receiver. This is a narrow filter (final bandwidth, 200 Hz) which is automatically centered on the received signal (whose frequency varies with the Doppler shift).

one counter which, by means of a time base deriving from the ultrastable oscillator, counts the frequency of the signal received after filtering by the phase circuit. /29


Coder
Modulation
Transmitter
X
Amplifier
Antenna
400–460 MHz
Ultrastable Oscillator
Receiver
Duplexer
Phase circuit
HF and MF stages
Demodulation
Phase meters
Doppler data
Phase meters
Distance data

All of the components are involved in the Doppler measurement.

Insofar as the distance measurement is concerned, the following devices are used:

one coder for generation of the subcarriers (this device forms the PFM train);

one modulator in the "transmission" unit;

one demodulator in the "receiving" unit (this is the phase comparer of the phase circuit);

phasemeters measuring the phase lags with the three subcarriers (Φ_A, Φ_O and Φ_1).

Main Characteristics

Transmitter

transmitting frequency: f_O = 462.270 MHz

transmission power: P_e = 4 W

Receiver

received frequency: 400.190 MHz ± 20 kHz

equivalent temperature of the receiving system T_e = 800 degrees K ($T_e = T_A$, antenna temperature, + T_R, receiver temperature).

sensitivity: - 133 dBm

for this value of the signal received, the frequency jitter with measurement of Doppler shift σ_f = 0.2 Hz.

maximum lock-on time 100 ms (use of switchable circuit bands).

Phasemeters

in the case of the sensitivity shown (- 133 dBm), the jitter with phase measurement σ_θ is on the order of 4 to 5 degrees.

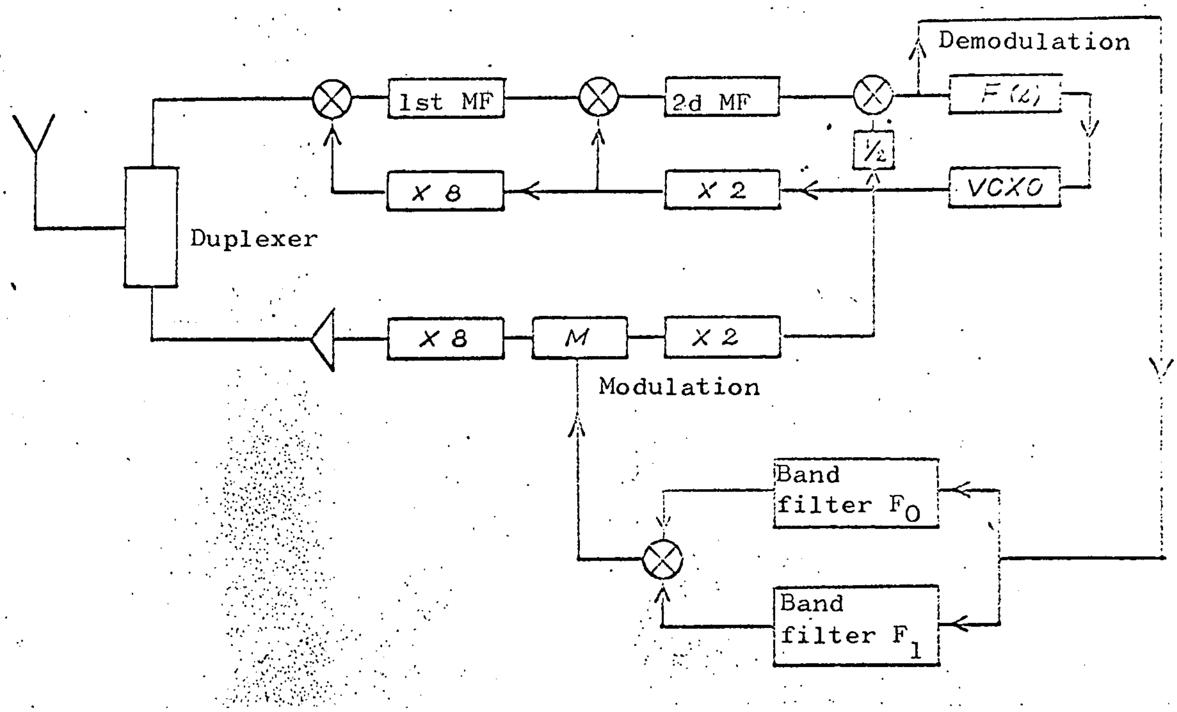
The satellite responder

The repeater includes:

one "phaselock" receiver with multiple band (all local oscillators derive from the VC X O oscillator);

one transmitter with its frequency multipliers;

two groups of filters, one centered on F_0, the other on F_1.



230

The video signal is demodulated upon outputting from the receiver, passes into the band filters and subsequently modulates the transmitter. The flow-chart of the responder is found above.

Main Characteristics

receiving frequency: 462.720 MHz ± 11 kHz;

sensitivity: - 133 dBm; for this signal value the S/N ratio in the phase-lock band amounts to 14 dB;

retransmitted frequency: 400.190 MHz ± 9.5 kHz;

power: 4 W.

Comments

The video filtering unit includes several band filters F_0 and F_1. Some are associated with a device for deviation index control which ensures that the amplitude of the arriving modulation signal is always constant notwithstanding /31 the amplitude of the video signal before filtering. An automatic cyclic commutator successively sends all outputs from the different filters to the modulator.

Command guidance makes it possible either to open up the video line (the modulator no longer receiving any signal), or, on the contrary, to directly connect the modulation output from the receiver to the modulation input of the transmitter (filtering no longer takes place and the video signal is therefore no longer limited in band).

Progress of the experiment

The experiment is devoted to the study of the two-way 400-460 MHz communications link. It consists in carrying out measurements involving signals received and errors in localization. Some of the parameters (transmission power, antenna gain, etc.) are varied, in this way allowing study and assessment of the relative magnitude of various causes of errors. The level of the signal received by the responder embarked on the satellite is transmitted by telemetry.

The localization errors have various causes. Some of the latter include: errors owing to noise in the communications' links, errors owing to interfering reflections of the beams on the ground or sea (multiple paths), ionospheric errors, etc.

Other Technological Experiments

The orbiting of the PEOLE satellite should allow flight qualification of a limited number of new components which will subsequently be used in the EOLE and D-2 programs, more particularly:

the EOLE vehicle, essentially the same as the one used for the PEOLE;

the satellite fairing of the D-2 with its pneumatic satellite-fairing separation device;

the system of "insulated core" thermal control;

thin-layer solar cells;

a silver-cadmium battery;

a pyrotechnical timing mechanism.

Satellite-Fairing Separation Device

The dynamic conditions "for acquisition" of the sun by the D-2 satellite requires a mode of satellite-fairing separation which only introduces extremely slight perturbations into the dynamics of the satellite. Now, the ground qualification of such a device is quite difficult, hence the advantage of testing it with the PEOLE.

System of "Insulated Core" Thermal Control /32

Thermal control of the PEOLE satellite is of the passive type. Satellite temperatures are only regulated by the working action of coatings of the outside structure, selected as a function of their thermo-optical properties (absorptivity and emissivity).

This is the so-called "insulated core" system. As will be done with the EOLE, the electronic equipment and battery are disengaged from the outside structure. The radiative disengagement is produced owing to screens fastened to the outside structure and ensuring a coefficient of radiative engagement with the latter on the order of only 0.10 to 0.15, depending on the parts.

The outside coatings were selected taking into account:

the fact that the orbits of PEOLE involve, at the minimum, a period of 30% shadow (they all pass into the earth's shadow). The total contribution of energy to the satellite is therefore slight with respect to the total surface;

the fact that power dissipated by the electronic equipment is slight (on the average, only a few watts, in orbit).

The greatest share of the outside structure is therefore coated either with aluminum paint (emissivity 0.31), or by an electrolytic gilding process (emissivity 0.05).

On the other hand, the "core" of the satellite is completely painted in black (emissivity 0.87) which allows production of a rather uniform range of temperatures.

As far as thermal calculations are concerned, the satellite is broken down into 112 parts (or isothermal modes). The temperature calculated for the satellite core is on the order of approximately 10 degrees C and practically constant for the whole orbit. The maximum temperature of the "hottest" part of the outside structure does not exceed 75 degrees C.

Thin-layer Cadmium-Tellurium and Cadmium-Sulfur Solar Cells

The experiment consists in studying the degradation in time of the current delivered by 4 modules of cadmium-tellurium cells and 4 modules of cadmium-sulfur cells.

Scientific Geodetic Experiment /33

Space geodesy has as its goal the simultaneous determination of positions in a given reference trihedron (navigation, positioning, cartography, hydrography, etc.) and parameters describing the earth's gravity field.

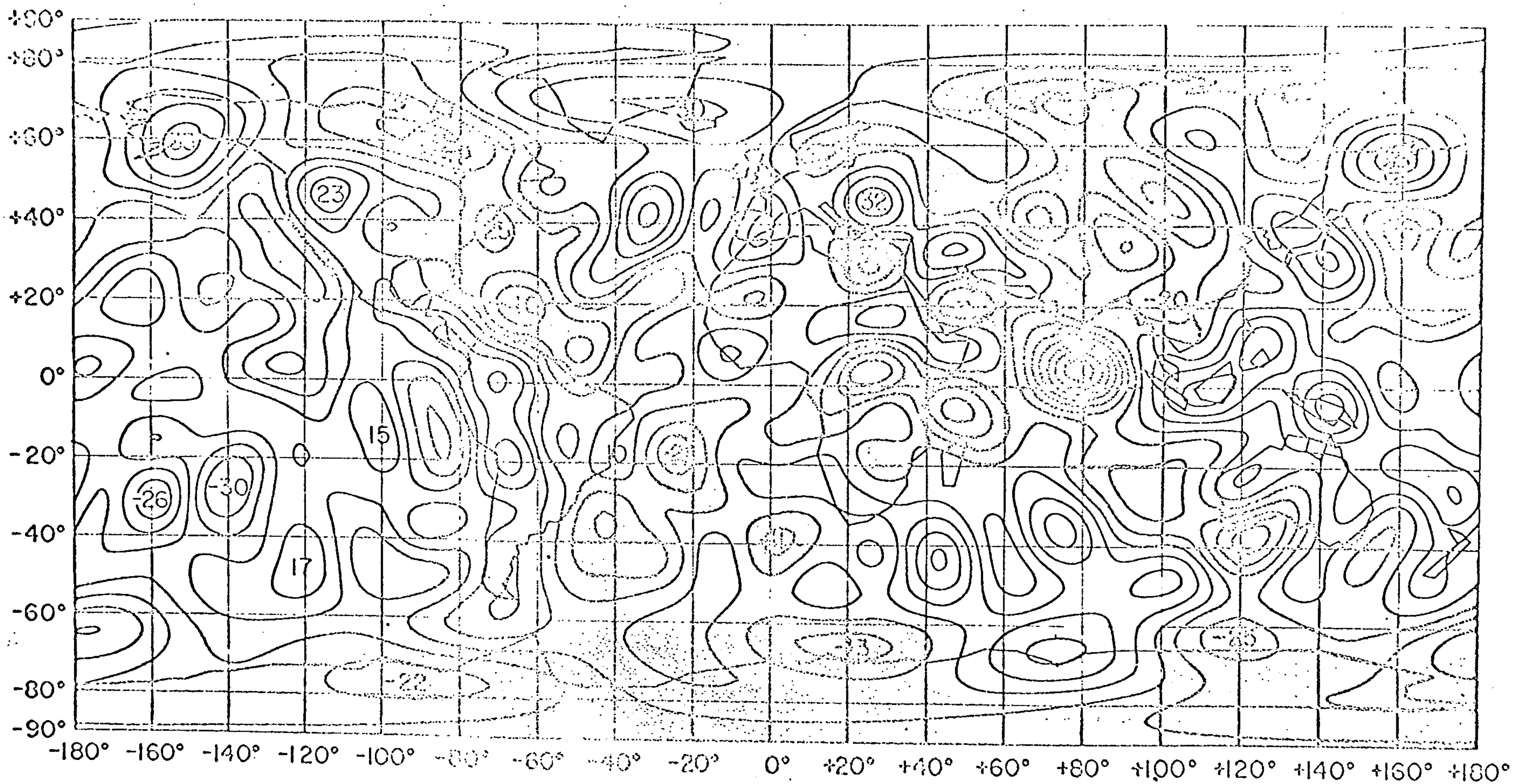
Dynamic geodesy is the term used to designate the methods of space geodesy causing the motion of the satellite to become a factor.

The PEOLE satellite is going to form one component of an experiment in dynamic geodesy which will take advantage of the special characteristics of the selected orbit, on one hand, and of progress made in laser telemetry techniques, on the other hand.

The orbit selected for PEOLE (altitude 750-800 km, inclination 15 degrees) provides it with great geodetic interest since, as yet, no satellite which could be used for such applications has been launched on an orbit with an inclination less than 28 degrees.

In addition, the performances of the launcher and the small eccentricity required for the gravity gradient stabilization ensures a mean altitude sufficiently high (from 750 to 800 km) for the disturbing effects of drag in the very high atmosphere to be easily taken into consideration.

Insofar as the techniques of laser telemetry are concerned, the first French and American findings were obtained starting in 1965. New developments have become a factor since that time such as construction of new sites, better performances and production of laser echoes on the moon.


+90°
+80°
+60°
+40°
+20°
0°
-20°
-40°
-60°
-80°
-90°
-180° -160° -140° -120° -100° -80° -60° -40° -20° 0° +20° +40° +60° +80° +100° +120° +140° +160° +180°
23
32
15
-26
-30
17
-22

Parallelly, the improvement in mathematical data processing methods and interpretation of findings in terms of geodynamics confirmed the necessity for supplementing the group of satellites used up until now by low-inclination satellites, provided with means enabling their very precise locatization.

In order to allow laser telemetry, a system of reflectors has been installed on PEOLE. It will allow maximum exploitation of the very advantageous orbital characteristics. It includes 44 reflectors, arranged around the UHF antenna (4) and at the outer end of the solar panels (8 groups of 5). These reflectors are formed by trirectangular trihedrons made of Suprasil 2 (synthetic silicon) which has been very precisely machined in such a mannor that any incident beam is sent off in a parallel direction after reflection on the 3 surfaces of the trihedron.

This is a purely passive system (without expenditure of embarked energy). It is therefore very economical and will allow, if the occasion should arise, experiments beyond the service life of the on-board equipment.

Goals

Two methods, quite different in their principle, are used in space geodesy:

the first one, purely geometrical, utilizes involvement of simultaneous observations from a same satellite beginning from several sites. This method, so-called geometrical geodesy, is very closely related to conventional triangulation and only supplies data on the relative positions of the sites;

the second one utilizes the motion of the satellite. This is called dynamic geodesy. The latter can:

either supply data on the geocentric positions of the sites, the potential field - and therefore the motion of the satellite - being assumed as known /35 (orbital geodesy, much in use for applications of navigation and semi-dynamic geodesy);

or allow improvement of our knowledge of the potential field of terrestrial attraction.

This last method, the most fruitful one, has been especially developed and utilized by the Smithsonian Astrophysical Observatory (SAO) which successively published 2 models of the earth (Standard Earth 1 in 1966 and Standard Earth

2 in 1969) for which "space" data (dynamic geodesy) were used successfully for the first time concurrently with data of the gravimetric type.

The geoid produced in this way (i.e. the equipotential surface which the oceans would describe in the absence of currents, tides and effects of the meteorological type) is depicted in the figure on page 32. Its details are already spectacular but important progress can still be made.

The ISAGEX equipment has the goal of crossing into a new era in knowledge of the earth. The contribution of PEOLE is quite significant, especially in the determinat on of zonal harmonics, those parameters described by that part of the potential field which is not a function of longitude and whose disturbing effects cause long-periodic fluctuations (on the order of 1 month to 1 year) of the eccentricity and inclination of the orbit, whereas the node and argument of the perigee undergo very pronounced secular displacements.

Since these perturbations are a function of inclination, the launching of PEOLE has a very special interest since no satellite provided with devices allowing it to be localized in so precise a manner exists with orbits inclined from 0 to 40 degrees.

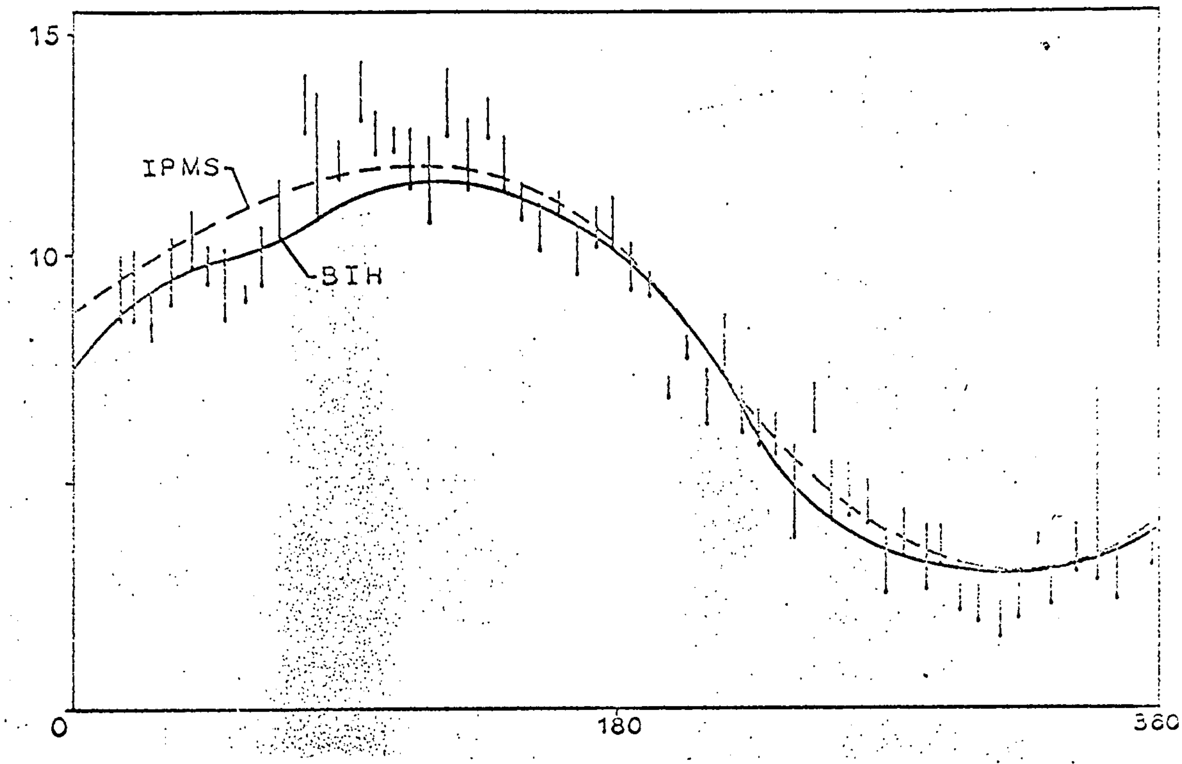
The very great resources employed in order to ensure tracking of this satellite within the scope of the ISAGEX program are the sign of international recognition of PEOLE's scientific mission.

A last aspect of the scientific experiment should be pointed out. The localization of the satellite will be done, no longer in order to study the motion of PEOLE but, considering the earth as a deformable elastic moving body, for the purpose of measuring its oscillations, the rate of spin and other parameters describing the dynamics of the earth-moon system.

More particularly, an attempt will be made to recover the motion of the pole by studying the 24 hour period oscillations of the inclination of satellites with laser reflectors.

Such a method, completely independent of the more conventional methods of positional astronomy, was successfully used by the Naval Weapons Laboratory of the U. S. Navy, using the Transit satellites of its Tranet navigational network.

The figure shown on this page illustrates the excellent agreement obtained with international services such as the International Polar Motion Service (IPMS) in Japan and the Bureau International de l'Heure (BIH) in Paris. /36



The Y component of the position of the pole for 1969. As abscissa, the days; as ordinates, the coordinates of Y in meters.

This type of application of geodetic satellites is basic for the study of our planet and astronomers, geodesists, oceanographers, geophysicists and radio-astronomers are already studying in common the future implications of these techniques which are going to make a considerable contribution to the improvement of our knowledge of the earth during the next 20 years.

The investment represented by the PEOLE satellite will therefore, to a certain extent, not be paid off in just a few months as is customary with embarked scientific experiments, but over a period of many years. This is not the very least of its qualities.

Laser Telemetry and Space Geodesy /37

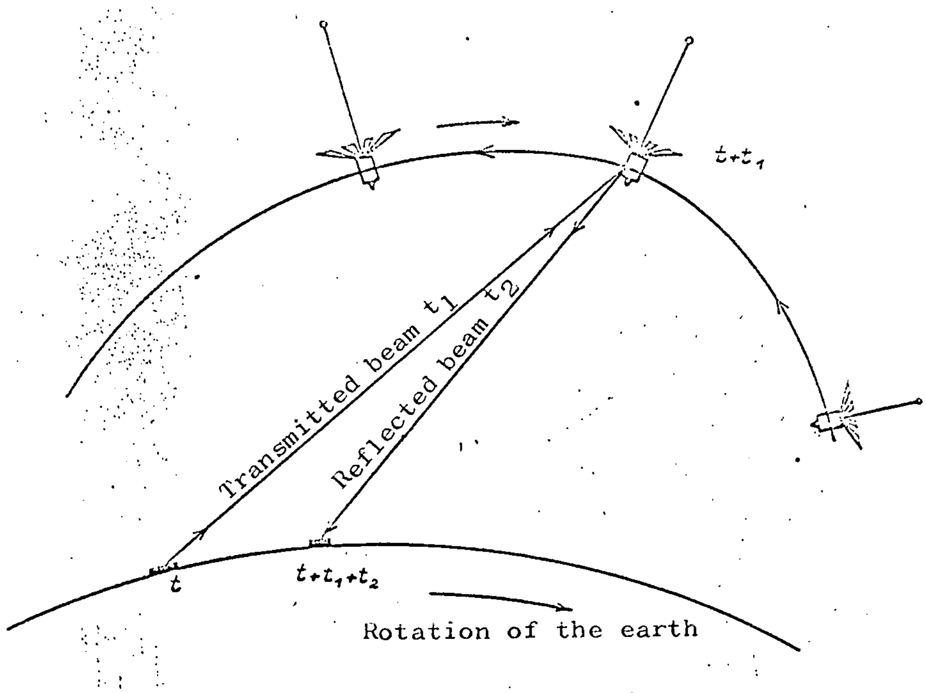
Let us review the principle, very simple and well-known in France since the 1967 Diadème experiment, of laser telemetry with satellite. In this technique, a very short laser pulse is sent in the direction of the satellite at an instant t. The laser reflectors, comparable to cat's eye reflectors, send the light back in a direction parallel to the incident beam. The transmitting station therefore receives a part of the reflected energy. The latter is amplified by a photomultiplier whose signal hatls a chronometer which the initial pulse had triggered.

The counter time produced in this way is the out-and-back propagation delay of the light between the site and the satellite. There is obtained in this way, after some simple corrections (planetary aberration, calibration, refraction), the distance at instant t between the station and the satellite. The precision varies, depending on the systems in service, from 1.5 to 0.5 meter, distance notwithstanding.

This measurement, repeated during the whole pass of the satellite above the site with a frequency, varying from 1 shot per second to 1 shot per minute, is compared, at the level of scientific processing, with a "theoretical" distance calculated according to a mathematical model and involving all the para- /38 meters which could have an effect on the motion of the satellite and concern the site. The data obtained in this way is processed statistically and allows adjustment of these parameters of which the most important ones are the positions of the sites on the earth and the characteristics of the field of terrestrial potential.

This measurement technique is often combined with less modern but complementary methods involving photography of the satellite on a background of stars and measurements of the Doppler effect, in the case of satellites which have very stable transmitters.

Simpler to use and more precise than radar measurements, laser telemetry requires no active system on board the satellite (the service life of the reflectors is, in principle, infinite and the first satellite - Beacon Explorer B - to be fitted with them, at the end of 1964, is still in use).



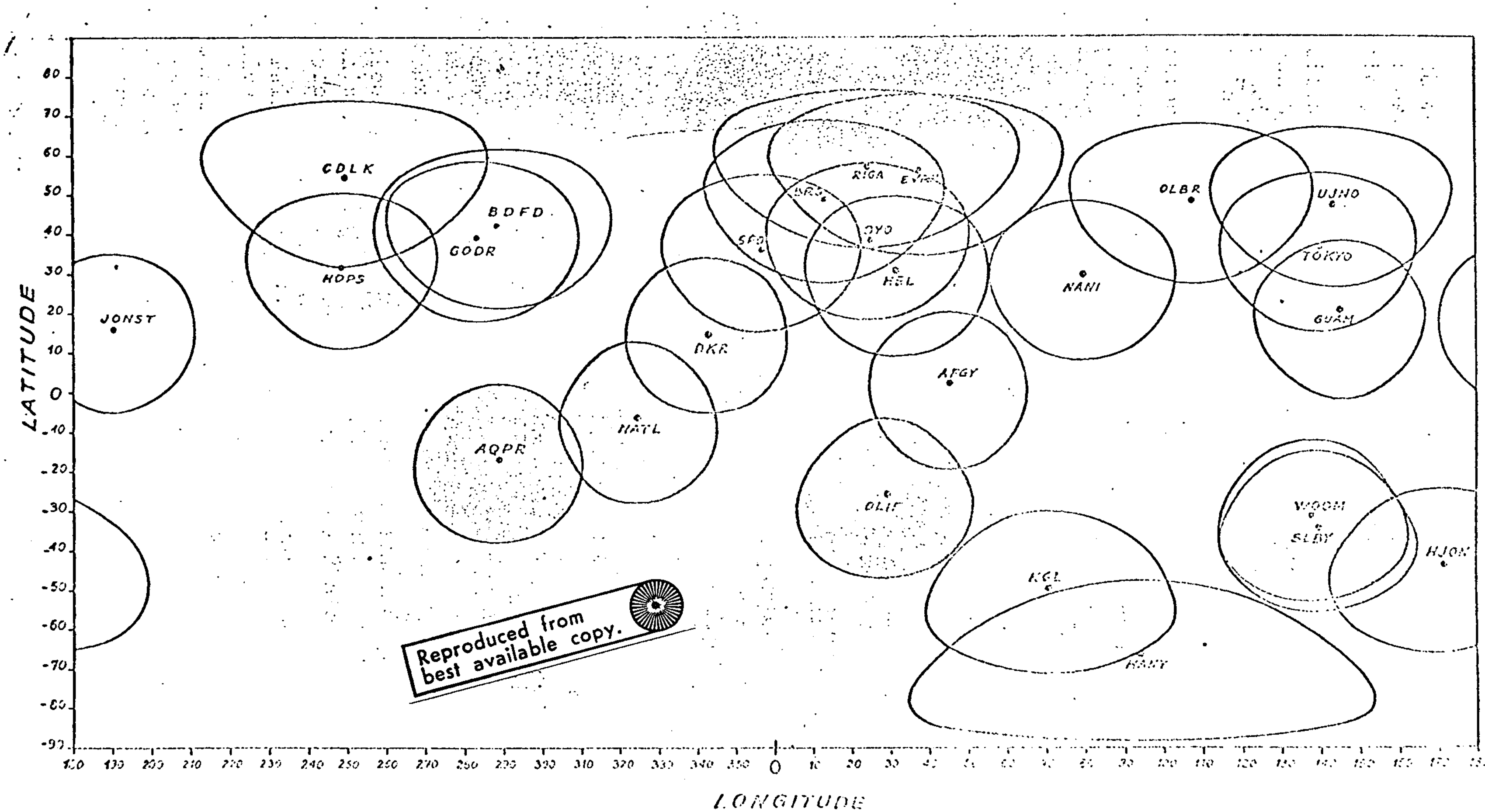
In addition, modern laser stations such as those belonging to NASA can operate on a day and night basis, thus ensuring an excellent distribution of observations in time without being limited by conditions of optical visibility such as is the case for cameras used for photography with a background of stars.

It should be stated in conclusion that the simplicity of analyzing laser measurements enables them to be processed automatically in real time. This quality is basic for all applications (positioning, determination of motions of tectonic plates and motions of the pole, studies of correlation with earthquakes...).

International Satellite Geodetic Experiment (ISAGEX)

The prospect of the PEOLE launch in 1970 and the great experience gained by French teams in space geodesy (Space Dynamics Group of the Meudon Observatory, Department of Space Geodesy of CNES, National Geographic Institute, Office of Longitudes) led CNES to issue, at the end of 1969, a veritable international "request for proposals" for participation in a worldwide space geodetic experiment, essentially based on the techniques of laser telemetry, i.e. the ISAGEX program.

The success of this effort came quickly and meetings of interested bodies took place in Paris during January 1970 and in Leningrad during June 1970 on the


LATITUDE
LONGITUDE
CDLK
BDFD
GODR
HOPS
JONST
AQPR
NATL
DKR
RIGA
AFGY
NANI
OLBR
TOKYO
GUAM
WOOM
KGL

occasion of the general meeting of COSPAR (World Committee for Space Research).

This experiment had three goals:

maximum exploitation of conventional and modern means of localizing satellites in order to produce a uniform system of observations of satellites supplied with laser reflectors - and more particularly PEOLE;

showing the feasibility of close coordination between networks of sites present at the worldwide level;

studying the capability for going beyond the conventional scope of space geodesy in order to deal with the more complex problem of geodynamics, i.e. the dynamics of the earth-moon system, their interaction and deformation (tides, motion of the pole, slowing down of the earth's rotation, etc.).

Sixteen countries have decided to take an active part in the ISAGEX program. /40
They are Australia, Belgium, Bulgaria, Czechoslovakia, Finland, German Democratic Republic, German Federal Republic, Greece, Japan, Netherlands, Soviet Union, Sweden, Switzerland, United Kingdom, United States and France.

In addition, other countries and many research centers of those countries mentioned above have expressed their interest in this international experiment and specified the research which they expect to carry out beginning from observations obtained.

Organization

Sixty-three sites belonging to these 16 nations but scattered throughout 32 countries are taking part in the observations. Among them are to be found:

15 laser telemetry sites;

30 sites having satellite tracking cameras;

10 sites having cameras only able to photograph flashes emitted by the American satellite GEOS-2;

8 sites equipped with Soviet cameras (NAFA 25) which are only used for the calculation of very precise orbital parameters necessary for "blind" laser shots in broad daylight.

Finally, out of these 63 sites, 11 are located close enough to the

Scientific Committee

PROJECT MANAGER (CNES)

Main Center
CNES
Brétigny Space Center

Center for calculating orbital parameters
Smithsonian Astrophysical Observatory

Operations Center for the GEOS-2 Satellite
NASA
Goddard Space Flight Center

Secondary center Eastern Europe	Secondary center USSR	Secondary center Western Europe and French Network	Secondary center	Secondary center
Ondrejov Observatory Czechoslovakia	Astronomical Council of the Academy of Sciences of the USSR, Moscow	CNES Brétigny Operations Center	NASA Goddard Space Flight Center	Smithsonian Astrophysical Observatory
5 tracking cameras	8 tracking cameras 8 NAFA cameras	5 lasers 4 tracking cameras 7 cameras observing GEOS-2 flashes 2 illuminating angle-measuring lasers and associated cameras	2 day and night lasers	8 lasers, including 5 day and night lasers 13 tracking cameras 1 illuminating angle-measuring laser and associated cameras

equator so as to be able to observe PEOLE whose inclination does not allow observation beyond ± 30 degrees of latitude.

Six new sites have, furthermore, been installed for the PEOLE launch. There is one camera and a French laser at Dakor, one NASA laser on the island of Guam and three lasers of the Smithsonian Astrophysical Laboratory in Peru, Braziland in the Union of South Africa in addition to the tracking cameras already placed by ISAGEX in these countries[2].

The zones of useful observations around the main sites are shown on the figure, page 37. The shaded zones show laser sites, the others corresponding to tracking cameras.

The coordination of so great a number of sites, with so differing operational modes, led to the setting up of a special organization whose flow diagram is provided by the figure on page 39.

A scientific committee, including 8 specialists in space geodesy from 6 countries and chaired by Professor Jean Kovalevsky, Astronomer at the Office of Longitudes, set up the scientific program and forwarded its recommendations to the Project Manager (Mr. Gérard Brachet, Department of Space Geodesy of CNES).

The latter is accountable for the "Main Center" installed at the Bretigny Space Center and is responsible for coordinating all of the sites through the intermediary of 5 secondary centers.

In addition, the Smithsonian Astrophysical Observatory at Cambridge, Massachusetts also ensures calculations of orbital parameters beginning from coarse observations coming from the sites and retransmitted by the main Center. /42

Finally, the Geodetic Operations Control Center (GOCC) of the Goddard Space Flight Center (GSFC) of NASA, near Washington, is responsible for operations concerning flashes from the GEOS-2 satellite.

The very heavy operations and communications load devolving on the Brétigny Space Center, in its capacity as Main Center as well as in its capacity as

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2. Installation of the French laser and optical sites (Dakar, San Fernando, Haute-Provence Observatory) was carried out with the assistance of CNES, Research and Testing Directorate and the National Center for Scientific Research.

Secondary Center coordinating the sites of Western Europe and those of the French network, is taken care of by the Brétigny Operations Center (COBY) under the leadership of a general project manager for operations, Deputy Project Chief (Mr. André Brevignon).

The project officer for the PEOLE scientific experiment and the French participation in project ISAGEX is Mr. François Barlier from the Paris-Meudon Observatory.

LISTING OF THE MAIN PEOLE CONTRACTORS PROJECT /43

MANAGEMENT AND SYSTEM INTEGRATION

CNES

Vehicle

thermal control	CNES
structure	SNIAS
solar generator	Radiotechnique
solar sensors	"
antennas	STAREC
extensible boom for altitude control	Fairchild

Electronic Equipment

command guidance	
telemetry	recovered on the FR-1
protection of batteries (overvoltages and undervoltages)	
400-460 MHz responder	CNES
converter	CROUZET
converter	MATRA
pyrotechnical timer (type D-2A)	E.M.D.
silver-cadmium battery	SAFT

CHRONOLOGY OF THE PEOLE LAUNCH /45

The launcher is completely set up with satellite and nose cone in place. All umbilical and base connections have been made and all embarked batteries and safety plugs are in place.

H - 22 hours to H - 19 hours

First equipment phase (installation of devices and measurement of resistances on safety plugs).

H - 19 hours 30 minutes

Examination of meteorological conditions forecast for H, before beginning of filling operations.

H - 19 hours to H - 16 hours

Topping off with freon tanks of the 2nd stage tilting device.

H - 15 hours to H - 11 hours 30 minutes

Topping off with UDMH (maintenance generator). This operation should be complete at the latest at 11 hours 30 minutes in order to leave at least 4 hours before filling with N_2O_4 in order to allow detection of leaks.

H - 11 hours

Pressurization (nitrogen) of the bottle of the 1st stage generator.

H - 8 hours to H - 4 hours 30 minutes

Topping off of N_2O_4

H - 4 hours 15 minutes

General test of countdown. Report of readiness condition of network sites.

H - 3 hours 30 minutes

Second equipment phase (check for absence of voltage, connection of all devices, placement of flight plugs).

H - 2 hours 30 minutes

Energization of telemetry control stands of the launcher.

H - 1 hour 30 minutes

Beginning of calibrations with telemetry sites. Energization of the automatic controller at the launch center and in the Control Room. Freedom of operation of radar and command guidance. Beginning of general inspection of launcher and preparation for withdrawal of tower.

H - 1 hour

Energization of the control panels at the launch command post. Lifting off of the gangways of the gantry.

H - 50 minutes

Inspection of the pyrotechnical lines to the junction rack for dangerous connections, without switching on.

H - 30 minutes

Opening of the tower hatches. Checking the shift of the tower for a short distance. Inspection of the pneumatic panel.

H - 25 minutes

Automatic check of the automatic controller and automatic control of the telemetry stand.

H - 20 minutes

Switching in of the pyrotechnical power supplies of the junction rack for dangerous connections (1 minute).

H - 15 minutes

End of calibrations of the telemetric equipment.

H - 11 minutes

Sending of all systems "green" by the launch command post. All readiness reports of the Guiana Space Center likewise become "green."

H - 10 minutes

General contact at the launch console. Starting of launch console camera. Beginning of retraction of gantry-tower.

H - 9 minutes 30 seconds

Safety engines placed in "safety" position.

H - 9 minutes

Launcher on outside power supplies. Automatic control of "ground" power supplies in load and of tilt electronics. Beginning of telemetry checks.

H - 8 minutes 30 seconds

Interrogation of responder by the Adour radar.

H - 7 minutes

Interrogation of responder by the Bretagne radar.

H - 4 minutes

Radar control reports: "Radar responder locked on."

H - 3 minutes 20 seconds

Automatic check of 1st stage guidance (without high pressure). Start of "guidance" recorder of the 1st stage. Start of magnetic recorders at the telemetry and localization sites. Confirmation "ready" of all resources located outside of the Guiana Space Center.

H - 2 minutes

Automatic check of 1st stage guidance, with high pressure.

H - 1 minute 15 seconds

Igniter motors placed in "armed" position. Automatic check of the "zeros" of the 1st stage nozzle.

H - 1 minute

Transition to internal batteries. Start of the auxiliary power unit of the /47 2nd stage (for the duration of the check). Automatic check of 2nd stage guidance and voltages of embarked power supplies.

H - 40 seconds

Start of the satellite timer device.

H - 20 seconds

Safety destruction engines placed in "armed" position. Start of "last instants" recorder.

H - 10 seconds

All other recorders in the sites placed in operation.

H - 8 seconds

Closure of solenoid valves for isolation of fuel overflow tanks. Start of internal timer devices of console.